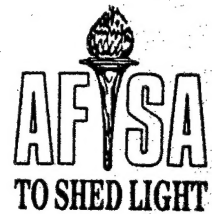


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**Air Force Center
for
Studies & Analyses**



STRATEGIC WEAPONS ASSESSMENT NOMOGRAPH

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STUDY BRIEFING

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In comparing the capabilities of strategic nuclear weapons, detailed models are often chosen to analyze a specific characteristic of each weapon to determine its relative merits. However, it is difficult to assess the overall capabilities of weapons without looking at these numerous characteristics simultaneously. Furthermore, reliance on detailed models can hinder analysts as well as decisionmakers from performing quick tradeoffs between these various characteristics in order to better determine the direction, if any, of indepth analyses. Finally, a better understanding of the interrelationships among these characteristics could provide helpful insights in guiding studies and decisions.

Based on these concerns, AF/SA requested an investigation into the interrelationships among the various strategic weapon characteristics. The intent was to develop a graphic model that could show all of these relationships on a single chart. In this way, quick desktop evaluations of strategic weapons could be made in order to provide insights into a weapon's overall capabilities. This briefing presents the resultant model, called the Strategic Weapons Assessment Nomograph (SWAN).

OVERVIEW

- THE DE FUNCTION
 - ASSUMPTIONS/CONSTRAINTS
- THE SWAN
- MODEL INSIGHTS

I will first discuss the Damage Expectancy (DE) function and the various weapon characteristics used in the model's construction. I will discuss the interrelationships of these characteristics and the assumptions/constraints I applied in order to build the model. With this background, I'll then present the model and how to use it. Finally, I will demonstrate some of the model's utility through various insights into strategic weapon capabilities. The real benefit of the SWAN lies in its ability to show the interrelationships of various weapon characteristics and how changes in each parameter impact a weapon's overall ability. Therefore it is this point that I'll emphasize throughout the course of this briefing.

STRATEGIC WEAPONS PARAMETERS

DE = DAMAGE EXPECTANCY = PD x PA

PD = PROBABILITY OF DAMAGE -- INFLECTING SPECIFIED LEVEL OF
DAMAGE GIVEN THE WEAPON DETONATES IN TARGET AREA

- CEP = ACCURACY OF WEAPON SYSTEM
- YIELD = ENERGY RELEASE OF WEAPON
- HARDNESS = TARGET'S BLAST STRENGTH (PSI)
- OFFSET = DESIRED DISTANCE FROM TARGET AT WHICH
DETONATION SHOULD OCCUR
- HEIGHT OF BURST (HOB) = HEIGHT ABOVE GROUND
FOR DETONATION

PA = PROBABILITY OF ARRIVAL -- PROBABILITY WEAPON DETONATES
IN TARGET AREA

- PLS = PROBABILITY OF PRE-LAUNCH SURVIVAL
- WSR = WEAPON SYSTEM RELIABILITY
- PTP = PROBABILITY OF TARGET PENETRATION
- C3 = PROBABILITY FACTOR FOR EXECUTION ORDER
RECEIPT/PROCESSING

To begin, the characteristics listed here are all interrelated to calculate Damage Expectancy or DE, defined as the probability to achieve a specified level of damage. DE can be subdivided into two parts:

First, Probability of Damage focuses on the target area and the probability of sufficiently damaging the target, given that the weapon arrives in the target area. This is a function of CEP, yield, target hardness, offset distance, and height of burst, defined here. Note that offset is commonly used in targeting multiple soft targets with a single weapon and in trying to minimize collateral damage.

Secondly, Probability of Arrival focuses on reaching and detonating at the target. The parameters of interest are listed here. Pre-launch survival involves such things as generation, warning time, and response time. Weapon reliability is determined from such things as maintenance records and test data. Penetrability is affected by the threat environment, and the weapon system's anti-defense systems and maneuverability.

THE DE FUNCTION

$$DE = PD \times PA$$

$$PD = F (CEP, Yield, HOB, Offset, Tgt Hardness)$$

$$PD = \frac{1}{2\pi} \int_0^{2\pi} \int_0^{\infty} P_d(r) \frac{1}{\sigma^2} e^{-\frac{(r^2 + x^2 - 2rx \cos \theta)}{2\sigma^2}} r dr d\theta$$

$$PA = PLS \times WSR \times PTP \times C3$$

In mathematical terms, these characteristics are interrelated by the expressions shown here. The PD function is basically a dual probability function. $P_d(r)$ represents the distribution of the probability that the target will incur severe damage at any distance (r) from the target. This is a function of target hardness, yield, and height of burst.

The remainder of the PD expression represents the distribution of the probability that the weapon detonates within the specified range from the target. This range is a function of CEP and offset.

Once PD is determined, the remainder of DE is simply a matter of multiplication. Thus we see the importance of PA since PD is on an equal weighting with all four of the PA parameters. This point is expounded on later.

Though special analysis of any one of these parameters can be important to a specific issue at hand, a simultaneous viewing of all such parameters can offer some interesting insights into the entire weapon system. This is the true advantage of the SWAN.

MODEL ASSUMPTIONS / CONSTRAINTS

- C3 = 1
- HOB = OPTIMAL (HIGHEST PD)
- OFFSET = 0
- TARGET HARDNESS (VNTK)
 - DAMAGE MECHANISM = STATIC OVERPRESSURE
 - ADJUSTMENT FOR SENSITIVITY TO PRESSURE DURATION = EQUIVALENT PSI LEVELS

Given these mathematical relations, several key assumptions/constraints were necessary in order to keep this very complex topic as simple and as usable as possible while still maintaining the model's utility. Thus only the parameters of greatest common interest were plotted, leading to the following assumptions.

C3 = 1, thereby assuming all messages are received and processed properly

HOB = optimal height, producing plots that give the highest possible PD for each yield against each target hardness; thus the model depicts the "best case."

OFFSET = 0, thereby focussing the model's applicability to one-on-one type analyses (i.e., single weapon on single target)

Target Hardness (defined using the VNTK system) assumes that static overpressure is the only damage mechanism that will cause severe damage to the target. There is also a special adjustment for pressure duration sensitivity needed in order to fix the equivalent psi curves that appear in the model.

To understand these target hardness assumptions, a brief explanation of the VNTK system is in order.

VNTK CONCEPT

CONCEPT REPRESENTS TARGET'S SUSCEPTIBILITY TO NUCLEAR WEAPON EFFECTS

VN NUMBER = ARBITRARY NUMBER DENOTING RELATIVE HARDNESS OF TARGET IN TERMS OF DAMAGE PROBABILITIES

T FACTOR = LETTER DENOTING TARGET SENSITIVITY TO TYPE OF PRESSURE WITH RELATIVE UNCERTAINTY LEVELS

K FACTOR = NUMBER BETWEEN 0 & 9, FOR ADJUSTMENT TO VN INDICATING SENSITIVITY TO VARYING PRESSURE DURATIONS AT DIFFERENT YIELDS. HIGHER NUMBER INCREASES PD

PSI RATING = F (VN,T,K,YIELD)

VNTK is simply a means of alphanumerically representing a target's susceptibility to nuclear effects. VNTK consists of 3 parts, as defined here. The Vulnerability Number (VN) is determined from information about target construction techniques and materials.

The T-factor denotes the primary damage mechanism (i.e., dynamic pressure, overpressure, or cratering) needed to achieve the desired damage. It also includes the relative uncertainty level in a target's response to this damage mechanism as one moves further away from the target.

Finally the K-factor denotes a target's sensitivity to the pressure duration of a nuclear detonation, with 0 indicating total insensitivity and 9 indicating extreme sensitivity. This factor is an adjustment to the VN. Since VN is based on a 20 kiloton yield, if $K > 0$ then the VN is adjusted downward for yields greater than 20 kt. This is because larger yields produce longer pressure durations and, if a target is sensitive to this duration, then a lower amount of pressure (equating to a lower VN) applied for a longer time will induce the same level of damage as a higher pressure (higher VN) applied for a shorter time. If $K = 0$, then the target is only affected by the amount of pressure applied, not how long. In this case, yield has no effect on the pressure rating of the target.

By taking VN, T, and K into account and, for $K > 0$, including the yield, an equivalent pressure rating in psi for the target is obtained.

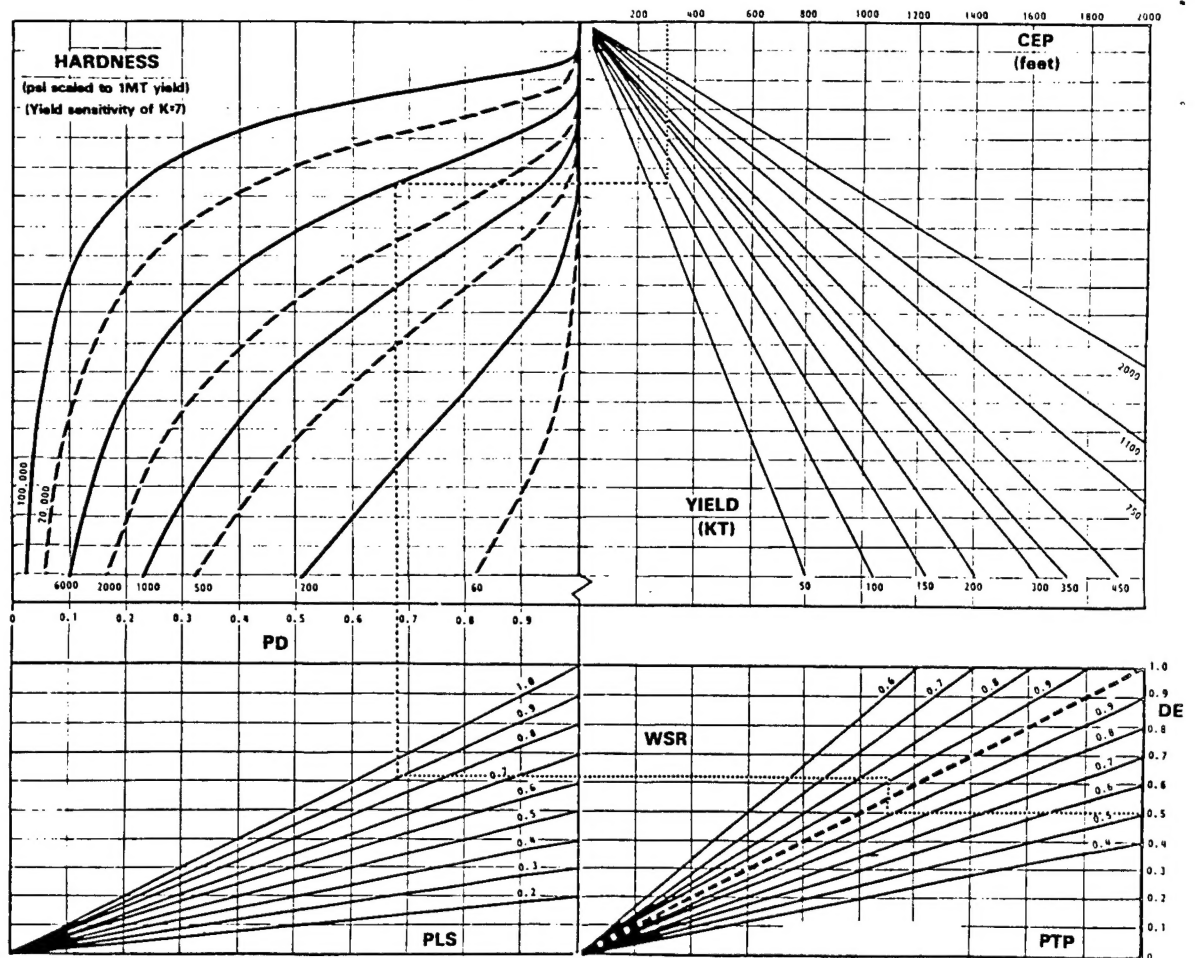
EQUIVALENT PSI CURVES

VN	+	K	+	YIELD	-	PSI
47.086		0		(ANY)		6000
47.086		3		100 KT		5179
47.086		7		100 KT		3741
47.086		7		1 MT		2543
51.796		7		1 MT		6000

Since the SWAN assumes that overpressure is the only damage mechanism, the T-factor was fixed for overpressure type targets, using a relative uncertainty of 0.2, which is the common practice for overpressure type targets. Thus VN, K, and yield combinations produce equivalent psi ratings.

As shown here, if $K = 0$, then yield has no effect on the psi. However, for a fixed VN, as K increases above 0 and as yield increases above 20 kt, the equivalent psi rating goes down. This means that the more sensitive a target is to pressure duration and the longer that pressure acts on the target, the less pressure is needed to inflict damage. On the other hand, as the last entry shows, if K and yield are fixed, then a VN can be found that equates to some desired psi.

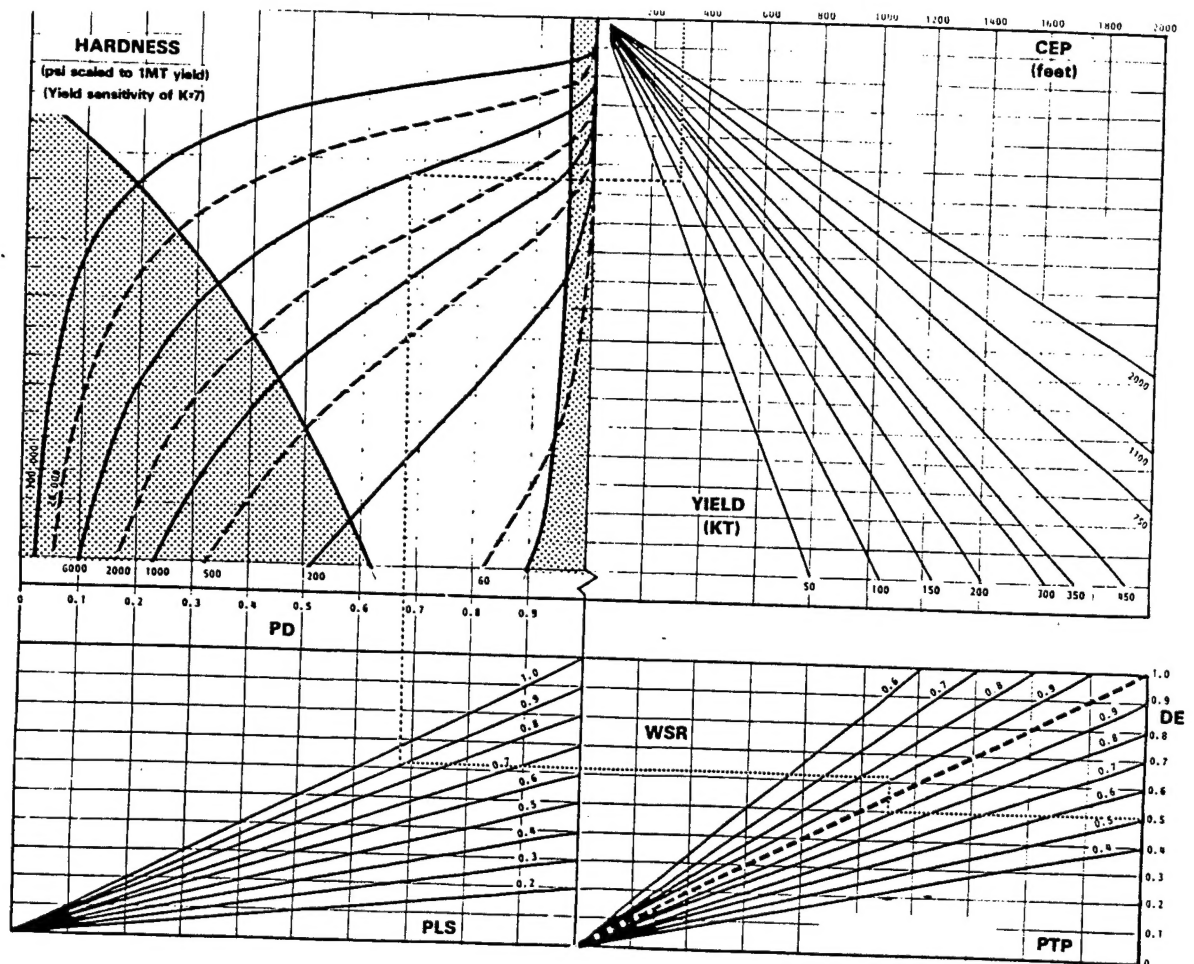
In order to build the SWAN, this latter case was important. Otherwise a different version of the SWAN would be needed for every K-factor and for every yield one wished to scale the psi towards. For the SWAN, specific psi curves were desired to enhance useability. To do this, the K-factor was set to 7 and the hardness curves were scaled to a 1 MT yield. The rationale behind these choices can be better demonstrated after the model is presented.



Therefore, pulling all of these characteristics into one chart, I present the weapons assessment nomograph. In general, it's a circular-type mapping structure where you plot from quadrant to quadrant in a circular fashion to arrive at the point of interest. Breaking it down further, the upper right quadrant shows CEP along the horizontal scale with specific yield lines plotted across the quadrant. The upper left portion shows PD horizontally with specific hardness curves plotted in psi. The lower left quadrant plots PLS and the lower right quadrant plots WSR and PTP with a common line at 1.0. To better understand the layout, I'll quickly trace through the example shown on the model.

Suppose we start at 300 feet CEP, move down to a yield of 100 kilotons, then over to 6000 PSI, down to .9 PLS, over to .9 WSR, down to .9 PTP, and finally over to a DE of about .50. The essence of the model is not simply to calculate values of DE, but more importantly to evaluate tradeoffs with any parameter to see its net effect on the weapon's capability. Since the model is based on damage expectancy, it can be viewed in two parts: the upper portion is related to PD, focusing on the target area; the lower portion is related to PA, focusing on getting the weapon to the target area. Thus the model can be used in a number of ways to arrive at the user's primary point of interest. The next slide shows one possibility.

As previously mentioned, the hardness curves are based on a 1 MT yield and a K-factor of 7. The rationale for these follows.

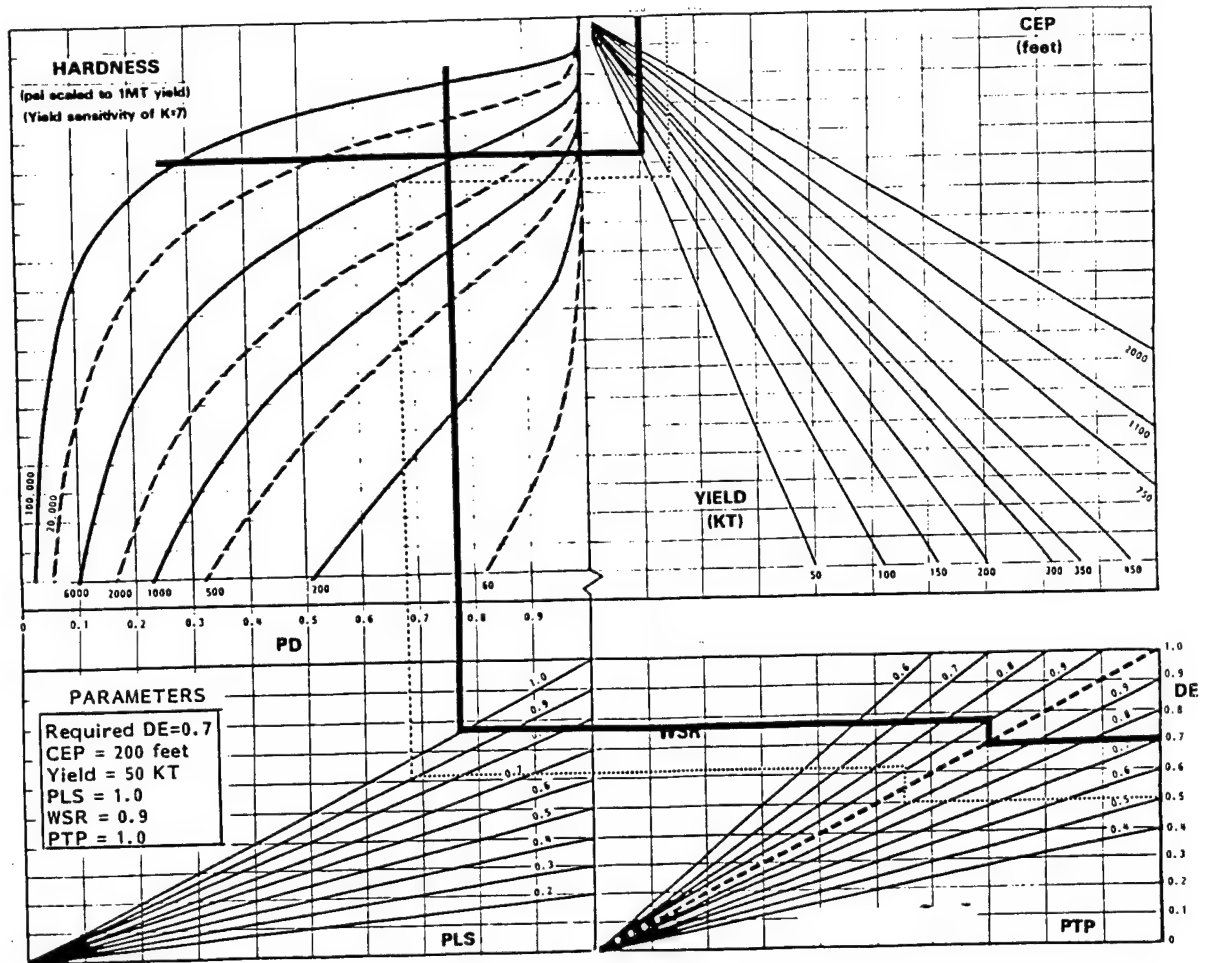


First, calculating values of PD for numerous combinations of CEP, yield, VN, and K-factor reveals that the K-factor has little effect on PD where the hardness curves have very steep slopes. Looking at the SWAN, this means the K-factor is of only minor concern when operating in the two shaded regions shown.

For the large unshaded region, PD varies significantly as K varies. In other words, as K increases from 0 to 9 for a fixed VN, T-factor, yield, and CEP, PD can increase by as much as 0.25, being most pronounced for the flatter slopes.

The greatest variations in PD occur for K equal to 6, 7, 8, or 9, while very small variations in PD ($\ll .1$) occur for $K < 6$. Thus I chose a K-factor of 7 to account for this region of greatest variability yet not overemphasizing it, as K = 9 would do. Furthermore, it so happens that PD values using K = 7 are approximately midway between K = 0 PD values and K = 9 PD values, all other parameters being equal. Consequently the SWAN should give reasonably accurate approximations of PD, regardless of the actual characteristics of the specific target one might consider.

Finally, based on the standard rule of practice in hardness ratings, I chose to scale the hardness curves to a 1 MT yield. This scaling was necessary since $K > 0$.



With an understanding of the model and its foundation now in hand, we now turn our attention towards the model's utility. Here is one possibility.

Suppose you have a specific weapon system and wish to know the hardest class of targets you could attack and still achieve a DE of 0.70. Using the weapon's parameters shown on the slide, first enter at 200 feet CEP. Move down to the 50 kt yield line and draw a horizontal line left from this point across all hardness curves. Then enter at a DE of 0.70 and move left to the 1.0 PTP line. Now move up to 0.9 WSR, left to 1.0 PLS and up until you intersect the horizontal line you drew. This point indicates you could attack targets hardened up to about 7000 psi.

Again, this is just one potential use of the model. Because of the model's layout, one could focus on only one or two quadrants to narrow his scope of interest. But whether one or all quadrants are used for a specific case, the interrelationships of the characteristics plotted on the SWAN reveal numerous insights into strategic weapon capabilities. It is for discovering these insights and for assessing the nuts and bolts of weapon capabilities that the SWAN was developed in the first place. In an effort to show the applicability of the model, I will discuss several varied examples. The Executive Briefing offers these same insights but from the standpoint of actual US and USSR forces.

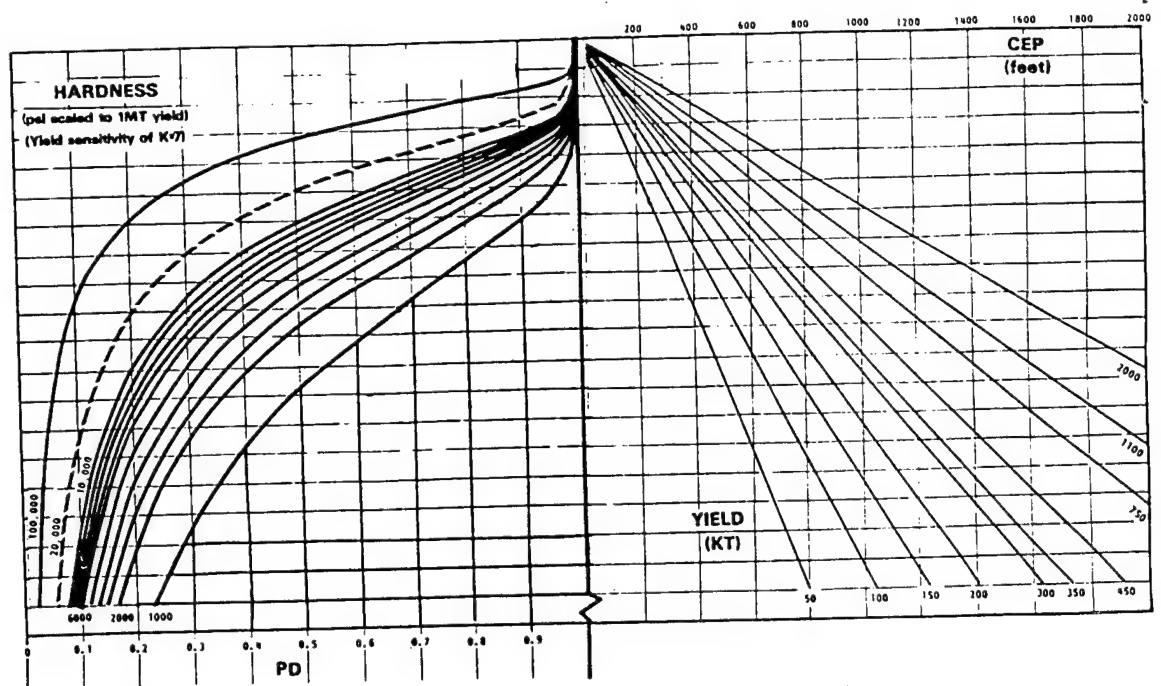
MODEL INSIGHTS

HARDNESS CURVE EFFECTS

- COMPRESSION EFFECT OF CURVES

Focussing on the upper left quadrant of the model, several points concerning hardness are revealed.

First of all, each curve has a knee where the slope changes its grade. Below the knee, improvements in CEP and yield improve PD slowly. However, in the area beyond the knee (where the curve is more horizontal) small improvements in CEP or yield would give large improvements in PD, offering incentive for that extra effort in force modernization.



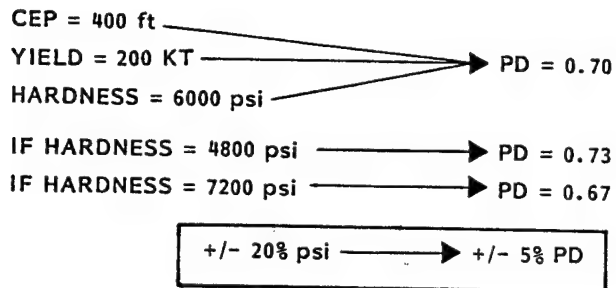
COMPRESSION EFFECT OF CURVES

1. BENEFITS OF HARDENING TO 2000 - 4000 psi
2. ORDERS OF MAGNITUDE NEEDED BEYOND THIS RANGE
3. LARGE MISESTIMATES AT HIGHER PSI ARE TOLERABLE

Secondly, the hardness curves compress together as psi increases. Thus moving from 0 to 2000 psi lowers PD more significantly than moving from 2000 to 4000 psi. This indicates that moving to the 4000 psi region offers impressive benefits in lowering the effective PD of enemy weapons. However, moving beyond the 4000 psi level requires increasingly significant improvements in hardness to attain any noticeable decreases in the expected PD, and thus to motivate any noticeable improvements in the CEP and yield of enemy weapons.

Thirdly, uncertainty in the hardness of a target could have only minimal impact on the CEP/yield combination needed. The next slide expounds on this.

MISESTIMATES IN HARDNESS



Suppose CEP = 400 feet, yield = 200 kt, and target hardness = 6000 psi. These give a 0.7 PD. However if the true hardness was 4800 psi, the PD only increases by 0.03. Likewise, if the true hardness was 7200 psi, the PD only drops by 0.03. Consequently for a variation in hardness of $\pm 20\%$, the variation in PD is only about $\pm 5\%$. This is true regardless of the psi level considered.

In absolute terms, 20% of 200 psi is only 40 psi, indicating the importance of good target definition at the lower end of the hardness spectrum. On the other hand, 20% of 100,000 psi is 20,000 psi, indicating a wide range of variability that has only negligible effect on PD.

MODEL INSIGHTS

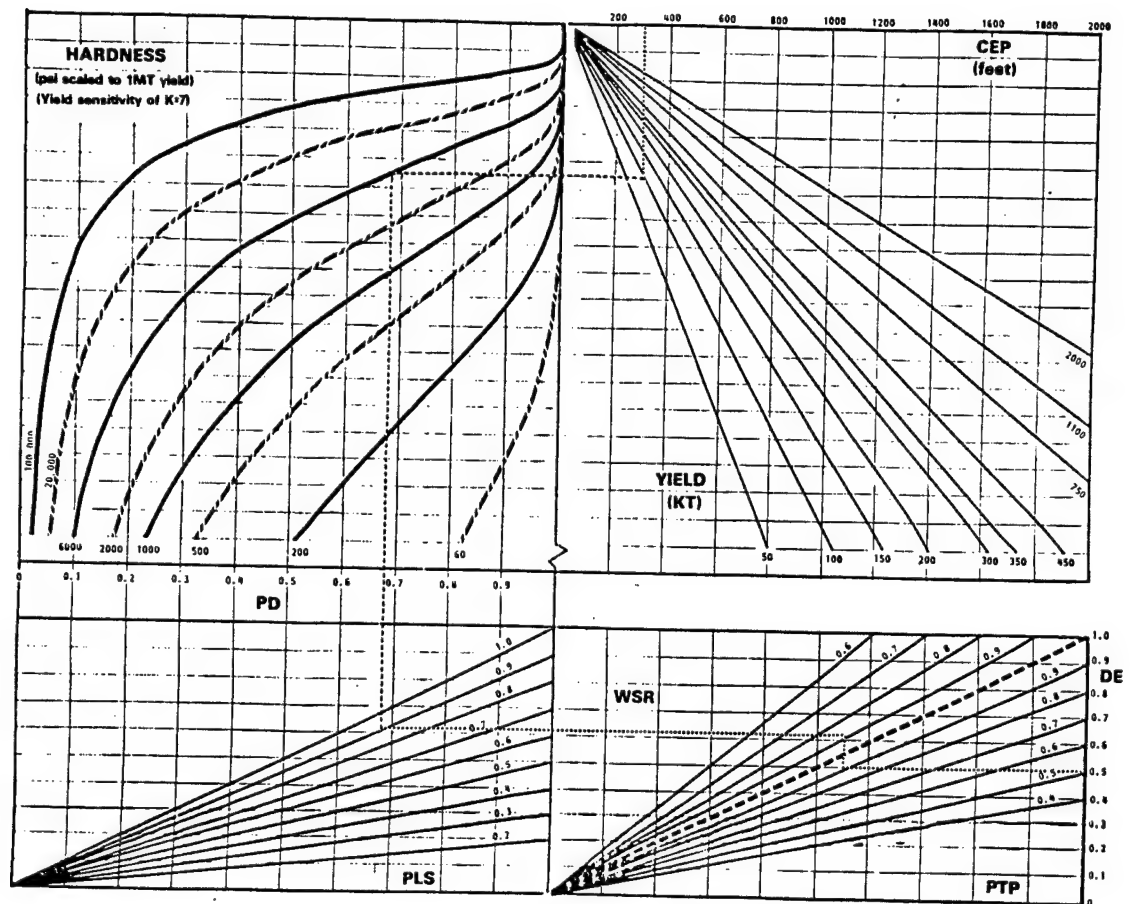
HARDNESS CURVE EFFECTS

- COMPRESSION EFFECT OF CURVES

▶ CONVERGENCE OF YIELD LINES

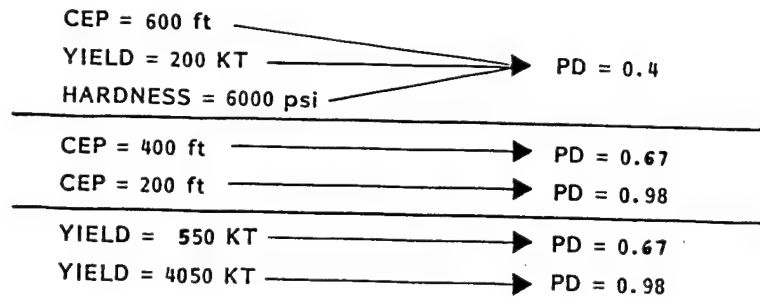
- CEP OVER YIELD IN MODERNIZATION

Adding the upper right quadrant to the discussions now, several points surface concerning what I call the convergence concept of the model.



Referring to the SWAN, note how all the yield lines converge at CEP = 0 as the hardness curves converge at PD = 1. This indicates that, as CEP approaches 0, yield and hardness become less and less important in terms of PD. Ultimately, at cep = 0, PD will equal 1 regardless of the yield or the hardness, thereby demonstrating the vast importance of CEP. To better illustrate this, consider the next slide.

BENEFITS OF CEP OVER YIELD



At CEP = 600 feet, yield = 200 kt, and target hardness = 6000 psi, we get a 0.43 PD. If modernization improves CEP to 400 feet, PD increases to 0.7. Further CEP improvement to 200 feet raises PD to 0.98.

By contrast, if CEP is fixed at 600 feet and we try to attain these same levels of PD through yield increases, one sees that drastic leaps in yield would be needed. In this example, a 400 feet drop in CEP equates to a 20 fold increase in yield (200 kt to 4 mt)! Thus CEP shows some definite benefit over yield.

The goal is to reach into this convergence region where all the yield lines and hardness curves come together. Once there, high levels of PD are possible against a wide range of very hard targets. To appreciably affect this requires large orders of magnitude in target hardness (i.e., 10's of thousands of psi). Furthermore, once convergence is reached, only relatively small changes in PD are attained by more modernization in CEP and yield for a given range of hardnesses.

These are just a few of the types of insights the model offers. But such insights are not confined to the upper portion of the model.

MODEL INSIGHTS

HARDNESS CURVE EFFECTS

- COMPRESSION EFFECT OF CURVES

CONVERGENCE OF YIELD LINES

- CEP OVER YIELD IN MODERNIZATION

► MODERNIZATION EFFORTS: PD vs PA

Though PD is important, so is PA. As mentioned earlier, $DE = PD \times PA$ and thus $DE = PD \times PLS \times WSR \times PTP$. Therefore PD receives equal weighting with all the factors of PA. One low value for any of these parameters could drastically reduce DE. Furthermore, though all values may appear quite good in and of themselves, the rippling effect on DE is significant. For instance a 0.9 value for all four parameters only gives a DE of 0.66. So we should strive to make all of these factors as high as possible, not just PD.

MODERNIZATION: PD vs PA

$$\text{TGTS KILLED} = F (\text{PD} \times \text{PA})$$

COST TRADEOFFS:

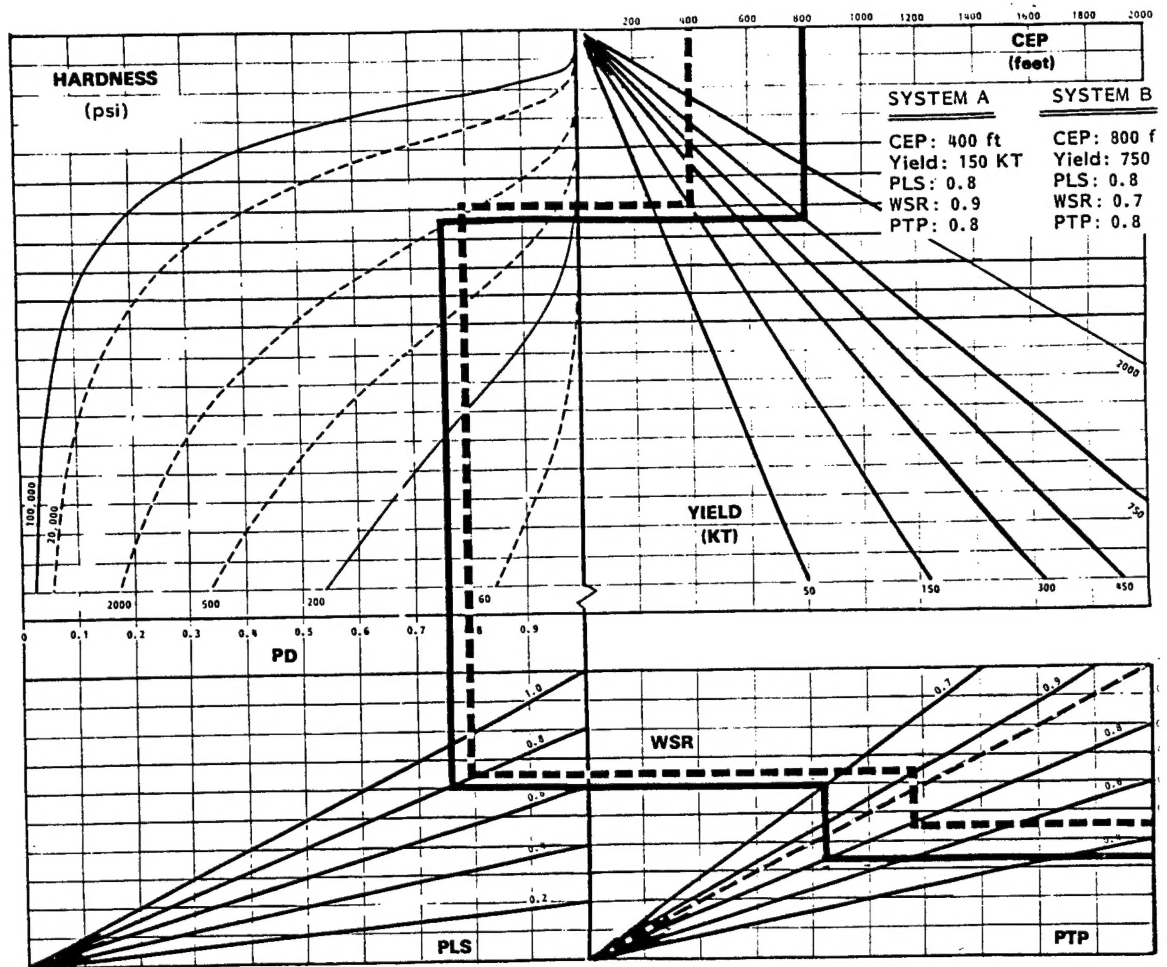
- CEP (TECHNOLOGY)
- YIELD (TECHNOLOGY)
- ALLOCATION (POLICY, STRATEGY, ENEMY TECH)
- WSR (TECHNOLOGY)
- PLS (POLICY, TECHNOLOGY, & STRATEGY)
- PTP (TACTICS, TECHNOLOGY, & THREAT)

Since DE is an indicator of targets killed, PD and PA are important in assessing strategic force capabilities.

As previously shown, the interrelationships of CEP, yield, and target hardness (or allocation) dictate the need to strive for the convergence region of the model. However, once there, high PD levels are achieved regardless of the target hardness. At that point, PA becomes the primary area of concern. And even if a particular system has not reached convergence, it may still be more advantageous to improve PA at possibly lower costs than to pursue changes in CEP and/or yield.

In addition, note that all of the parameters involve technology in some fashion. However the PA parameters are also determined from numerous subjective concepts and judgements. DE could therefore improve through areas other than weapon specifications, such as policy or strategy. This could offer significant dollar savings as well as time savings in implementing such changes.

The important point is that the model can show the cost benefits of making small improvements in multiple weapon characteristics instead of a massive effort in one area. If costs could be assigned for incremental improvements in each characteristic, a cost analysis could be made to find a near "optimal" system based on operational needs.



As a final example, consider two generic weapon systems. Both are compared against the same 2000 psi hardness. As shown, system A has a much better CEP than system B, and is thus able to achieve a higher level of PD, despite its substantially smaller yield. This illustrates the importance of CEP and the convergence concept, as previously discussed.

Secondly, system A has a higher reliability (WSR) than system B. Consequently the effectiveness gap between these systems becomes even wider. That is, the difference in PD values due to system A's greater accuracy is 0.05, but the difference in DE values due further to system A's better reliability is 0.13. This illustrates the importance of PA as well as PD.

The carryover of this example to actual strategic force issues should be quite apparent. Such plots could be made to compare systems within a TRIAD leg, systems of different TRIAD legs, and Soviet and US forces, to show tradeoffs among various characteristics being considered/projected for a modernization effort, and so forth. Thus the SWAN could serve as a quick reference tool into strategic force issues, serving as a stepping stone to more detailed analysis.

SUMMARY

THE SWAN

- SHOWS PARAMETER RELATIONSHIPS
- OFFERS KEEN INSIGHTS
 - COMPRESSION OF HARDNESS CURVES
 - CONVERGENCE OF YIELD LINES
 - TRADEOFFS BETWEEN PD and PA
- IS BOUND BY GRAPHIC ACCURACY
- IS BEST SUITED FOR
SINGLE-WEAPON-TO-SINGLE-TARGET ANALYSIS

As discussed, the SWAN clearly shows the interrelationships between key strategic weapon characteristics. Clear approximations of weapon capabilities are possible. However, of greater benefit are the insights into nuclear weaponry that the model reveals. Such concepts as hardness compression, hardness misestimates, CEP/yield convergence, and PA/PD tradeoffs are just a flavor of the utility of the SWAN.

In addition to these general insights, the model is quite useful in specific strategic issues. One could analyze force trends, compare weapon systems, and even provide visual support and understanding for strategic force issues and testimony.

Yet, when applying the SWAN to any investigation, its limits must be considered. Though ballpark values of PD and DE can be obtained, the model is bound by graphic accuracy and the assumptions concerning target hardness definition. Assumptions also limit it to single-weapon-on-single-target analysis.

Nonetheless, the SWAN is not intended to be a bottomline analytical tool, but instead serves as a quick reference to guide discussions, detailed analyses, and decisions concerning strategic weapons. In this light, its utility is quite apparent.